STUDY ON PSEUDOSTATIC TEST OF FRAME-SUPPORTED MULTI-RIBBED SLAB STRUCTURE

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ABSTRACT:

This paper presents the results and discussions of experimental study on FSMRSS specimen. The specimen is four scaled models (three 1/2 scale two-storey two-bay models and one 1/3 scale three-storey two-bay model) of FSMRSS. The pseudo-static experiments of the specimens have been executed. The seismic performances under low cyclic loadings, such as the failure procedure, failure mode, bearing capacity, deformation features, stiffness, hysteresis characteristic and anti-collapse performance, are studied. The experimental results show that the failure procedure of FSMRSS specimen take place in the order of infilled silicate bricks, reinforced concrete rib beams, reinforced concrete rib columns, outer frame and supporting frame; the deformation and failure mainly concentrate on second storey (multi-ribbed slab structure storey), the specimen shows good load carrying capacity even in large deformation condition and high restoring characteristics. The conclusion obtained provide reliable basis for the application of FSMRSS to the buildings with large space at the bottom.

KEYWORDS: Frame-supported multi-ribbed slab structure (FSMRSS), Pseudo-static experiment, Seismic performance analysis

1. INTRODUCTION

Frame-supported multi-ribbed slab structure (FSMRSS) is a new structural system developed by the Graduate School of Building Engineering New Technology of Xi'an University of Architecture & Technology. Because of the complexity of the structure and absence of data information, to perform a step-by-step force-displacement response analysis of structure, an experimental investigation of the specimens is required. Furthermore, for seismic design and evaluation purposes, where a nonlinear dynamic time-history analysis may be required, a hysteresis model is necessary. In this paper, the pseudo-static experiments of the specimens of four scaled models (three 1/2 scale two-storey two-bay models and one 1/3 scale three-storey two-bay model) have been executed. The control parameters of the hysteresis model can be calibrated using experimental data. The main objectives of the study are to grasp the earthquake response behavior of the FSMRSS and evaluate the basic seismic performance of the structure.

2. EXPERIMENTAL DATA

2.1 Specimen Design

The prototype of specimen is an eight-storey frame-supported multi-ribbed slab structure being designed according to China building criterion. For simplicity, specimens were designed to be a plane structures where bottom frame was one storey and upper multi-ribbed slab structure was 1~2 storey. The serial numbers of specimens were KZML-1, KZML-2, KZML-3 and KZML-4 respectively. KZML-1 was a 1/2scale two-storey two-equal-bay models without hollow, in which multi-ribbed wall slab were laid on one bay trimmer beam with cement mortar pasting and in anther bay the wall was connected with trimmer by jointing, to take into account the construct of juncture for influence of bearing capacity; KZML-2 was a 1/2scale two-storey two-unequal-bay models without hollow in order to consider the influence of height to span ratio of two storey multi-ribbed wall slab and height to span ratio of trimmer beam; KZML-3 was a 1/2scale two-storey two-unequal-bay models with hollow to reflect the influence of hollow; KZML-4 was a 1/3 scale three-storey two-unequal-bay models without hollow to investigate deformation features and bearing capacity of transform storey. The wall thickness of 1/2scale models was 100mm while 1/3 scale model was 75mm. The materials of specimen were homologous with prototype which resembling relations were shown in Table 1. The dimensions and details of specimens were shown in Figure 1~ Figure 4. Test properties of materials of specimens were shown in Table 2~ 4.

Table 1 Resembling relations of models

Specimen	E、G、ν	Length	Area	Mass	Displacement	Stress	Force	Bending
Prototype	1	1	1	1	1	1	1	1
1/2scale model	1	1/2	1/4	1/4	1/2	1	1/4	1/8
1/3scale model	1	1/3	1/9	1/9	1/3	1	1/9	1/27

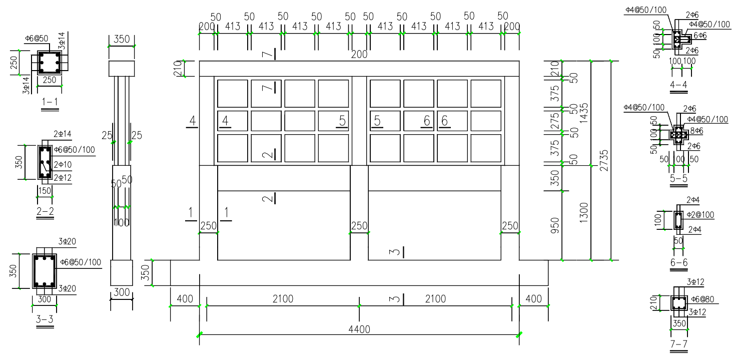


Figure 1 Geometry dimensions and reinforcement details of specimen KZML-1

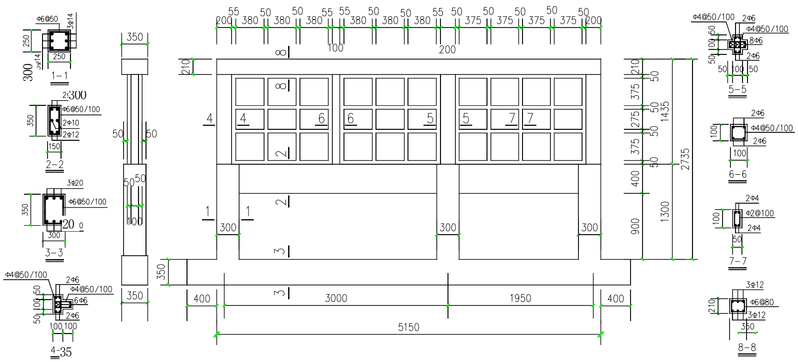


Figure 2 Geometry dimensions and reinforcement details of specimen KZML-2

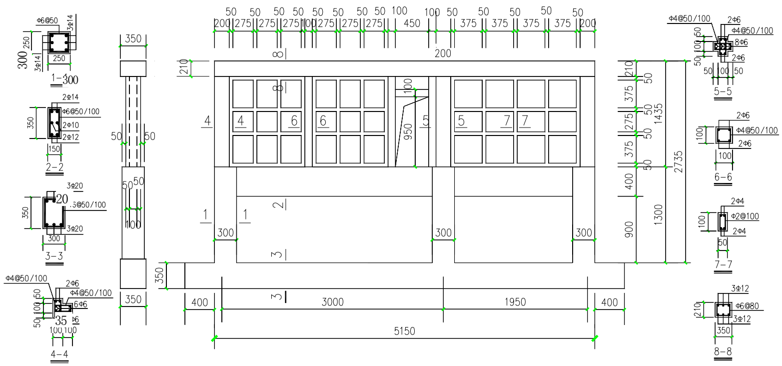


Figure 3 Geometry dimensions and reinforcement details of specimen KZML-3

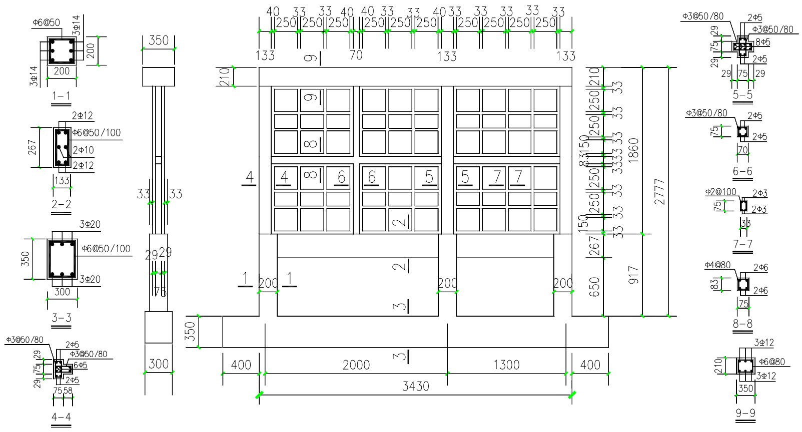


Figure 4 Geometry dimensions and reinforcement details of specimen KZML-4

Table 2 Test properties of materials of steel bars

Specification	f_y (MPa)	ε_y (με)	f_u (MPa)	E (MPa)
φ2	——	——	318	——
φ3	——	——	283	——
φ4	595	6000	671	9.92×10^4
φ5	408	2400	621	1.70×10^5
φ6	415	1700	531	2.44×10^5
φ10	463	2400	516	1.93×10^5
φ12	432	2500	503	1.73×10^5
φ14	403	2210	590	1.82×10^5
φ16	469	3000	628	1.56×10^5

Table 3 Test properties of materials of concrete

specimen	bottom frame		rib beams, rib columns		outer frame, top beam	
	f_c (MPa)	E ($\times10^4$MPa)	f_c (MPa)	E ($\times10^4$MPa)	f_c (MPa)	E ($\times10^4$MPa)
KZML-1	34.5	3.14	31.1	3.03	26.8	2.87
KZML-2	34.5	3.14	28.7	2.74	34.7	3.14
KZML-3	32.3	3.07	28.2	2.93	34.7	3.14
KZML-4	35.4	3.16	29.3	2.97	28.9	2.96

Table 4 Test properties of materials of silicate bricks

γ (kN/m^3)	f_c (MPa)	f'_m (MPa)	f_t (MPa)	E (MPa)
7.32	4.15	2.75	0.42	2.25×10^3

Notes: E = modulus of elasticity, G = modulus of shearing, ν =Poisson's ration, f_y =yield strength, ε_y =yield strain, f_u =ultimate strength, γ =dried unit weight, f'_m = silicate bricks prism strength, f_c =compressive strength, f_t =tensile strength

2. 2 Loading System

The pseudo-static experiments of the specimens have been carried out. The loading system of test was shown in Figure 5. Firstly, it brought vertical loading to bear on the specimen to maximum value about 500kN according

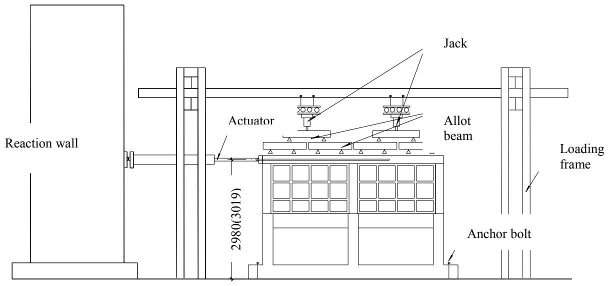


Figure 5 Loading system

to condition of loading system, and then unloaded to an invariable value about being 331kN, 385kN, 385kN and 236kN for KZML-1, KZML-2, KZML-3 and KZML-4 respectively. Secondly, it started to load horizontal loading by using loading-displacement mixing control method, in which loading control was adopted by monotone loading with every step of 10kN/20kN before the specimens yielding, and displacement control was adopted with multiples of yielding displacement cycling three times under every step after yielding.

2.3 Experimental Result

2.3.1 Failure procedure

Failure phenomena of the specimens are shown in Figure 6~9.The failure modes of the specimens presented shearing failure characteristic. Under low cyclic loadings, for specimen KZML-1, at initial stages of loading, infilled silicate bricks of multi-ribbed wall slab appeared several slight cracks; loading to metaphase, the cracks of infilled silicate bricks increased markedly, and extended to reinforced concrete rib beams and rib columns; continuing loading, there is a small cracking and slipping between interface of the wall and trimmer beam; loading to yielding of the specimen, interface of the wall and trimmer beam arose big cracking and apparent slipping; after entering cycles loading of displacement control, infilled silicate bricks desquamated slightly in the seaming, failure of specimen KZML-1 mainly took place in the bottom frame post, occurring of post root plasticity hinge brought on serious deformation resulting in specimen not being continued loading. Failure of specimen KZML-2, KZML-3 and KZML-4 mainly concentrated on second storey (multi-ribbed slab structure storey) while damage of frame-supported post was slight, trimmer beam showed shearing failure of beam end; failure procedure of second storey wall took place in the order of infilled silicate bricks, reinforced concrete rib beams, reinforced concrete rib columns, and outer frame cracking until the infilled silicate bricks desquamated in a big area, the wall degenerated into small frame, end of numerous rib beams came into being plasticity hinges, and local concrete of outer frame post root was crushed partly.

Figure 6 Failure phenomena of KZML-1

Figure 7 Failure phenomena of KZML-2

Figure 8 Failure phenomena of KZML-3

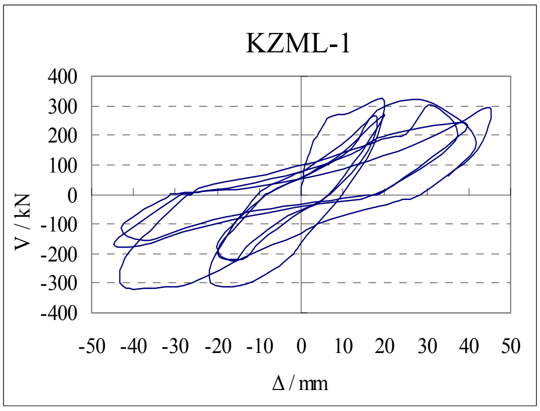
Figure 9 Failure phenomena of KZML-4

2.3.2 Main experimental result

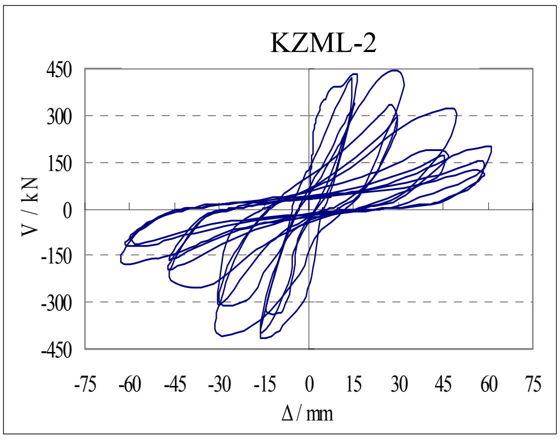
Cracking, yielding, ultimate and failure loads of the specimens are shown in Table 5, in which cracking load is the load that the infilled silicate bricks of multi-ribbed wall slab appear numerous apparent cracks, failure load take about 85% of ultimate load. Hysteresis curves of the specimens are shown in Figure 10, in which V is horizontal loading acting on the top of the specimen while Δ is horizontal displacement at the top of the specimen.

Table 5 Load-resisting capacity index of specimens

Specimen	Cracking		Yielding		Ultimate		Failure	
	V_c (kN)	Δ_c (mm)	V_y (kN)	Δ_y (mm)	V_u (kN)	Δ_u (mm)	V_m (kN)	Δ_m (mm)
KZML-1	160	2.5	280	10	320	20	270	45
KZML-2	180	1.3	440	15	443	30	370	48.5
KZML-3	180	1.4	430	15	430	15	360	32
KZML-4	100	2.6	260	20	260	20	221	49



(a)



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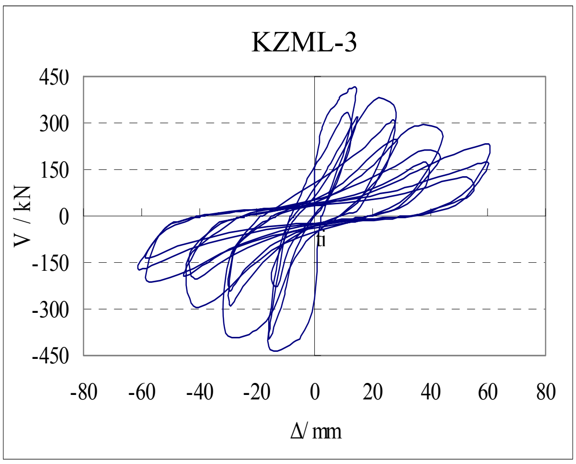

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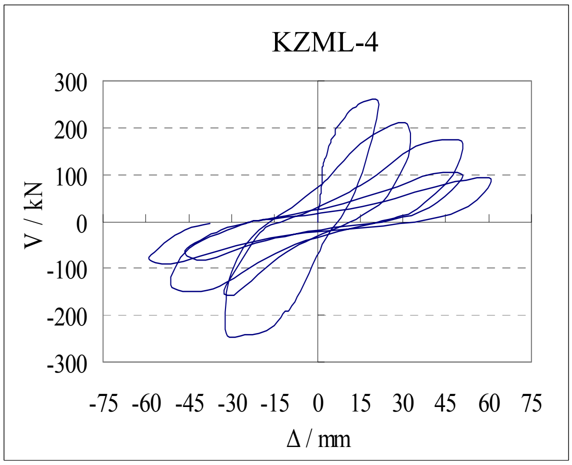

(d)

Figure 10 Hysteresis curves of the specimens

3. SEIMIC PERFORMANCE ANALYSIS

3.1 Bearing Capacity

Table 5 shows that the specimens have big bearing capacity. The skeleton curves of the specimens are shown in Figure 11. It can be seen from Figure 11 that shapes of skeleton curves of the specimens remain resemblance on the whole before yielding. At later stages of test, after going beyond the limits of ultimate load-resisting capacity, specimen KZML-1 brought on a big deformation since post root plasticity hinge occurred; the bearing capacity of specimen KZML-3 declined faster than KZML-2 because of weakening of hollow to the wall; the bearing capacity of specimen KZML-4 declined also faster than KZML-2 because of the absence of floor restriction between the second storey and third storey.

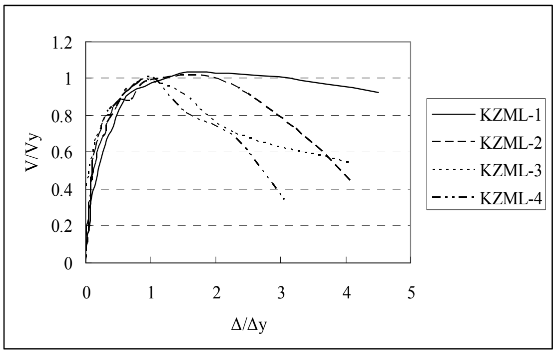

Figure 11 Skeleton curves of the specimens

3.2 Hysteresis Characteristic

From hysteresis curve of the specimen KZML-1(shown in Figure 10(a)), it can be seen that hysteresis loop is plump, which demonstrate there is not serious damage in the inside of the specimen. The end of test is because of abrupt increase of deformation of the specimen, resulting in a big remainder of deformation. The peculiarity of hysteresis curve shows a coincidence with the experimental phenomena.

The hysteresis curves of the specimen KZML-2, KZML-3 and KZML-4 show some characteristics as follows(shown in Figure 10(b) (c)) (d)): Before cracking of the wall, hysteresis curves appear approximately beeline, remainder deformation of the specimens is small, while specimens are basically in the elastic state; after cracking of the wall, the hysteresis curves appear shuttle shape, stiffness of the walls decline, but the bearing capacity of the specimen continue to increasing, area of hysteresis loop gradually enlarge, lateral deformation increase rapidly, around ultimate loads hysteresis loop is plump; along with increasing of horizontal loads , cracking of the specimen multiple, elongate, widen, and stiffness decay, after unloading remainder deformation of the specimens is apparent; over ultimate loads, hysteresis loop display obvious slip pinching and appear arc since at this time inside the specimen cracks have widened, and after unloading stiffness of being opposite to loading can be represented only in the positive cracks have closed; as arriving at ultimate displacement, slip-pinching effect of hysteresis loop is more prominent, hysteresis loop appear reverse “s”, reflecting that shearing-slip of the specimen is big. As stated above, frame-supported multi-ribbed slab structure has good energy dissipation capacity and hysteresis performance.

3.3 Stiffness Decay

In order to reflect stiffness decay characteristic of frame-supported multi-ribbed slab structure under low cyclic loadings, average stiffness of every cyclic loading denoted as K_i as follows:

$$K_i = \frac{|V_i| + |-V_i|}{|\Delta_i| + |-\Delta_i|} \tag{3.1}$$

in which V_i is the positive horizontal loading at i cyclic; $-V_i$ is the direction opposite or negative horizontal loading

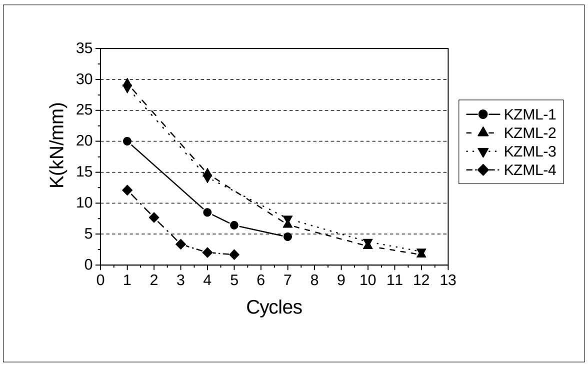

Figure12 Stiffness decay of the specimens

at i cyclic; Δ_i is the displacement under the positive the horizontal loading; $-\Delta_i$ is the displacement under the direction opposite or negative horizontal loading.
Stiffness decay curves of the specimens KZML-1, KZML-2, KZML-3 andKZML-4 are given in Figure12. It is seen that initial stiffness of frame-supported multi-ribbed slab structure is big, however, stiffness of the specimens decline faster since the infilled silicate bricks of multi-ribbed wall slab of the second storey structure crack severely or desquamate in a big area after yielding. It explains that stiffness of frame-supported multi-ribbed slab structure can be changed by sacrifice of the infilled silicate bricks, so the earthquake responses of the structures can also be decreased by avoiding of predomination period.

3.4 Anti-collapse Performance

Although the failure of specimen KZML-1is mainly because of occurring of bottom frame post root plasticity hinge bringing on serious deformation not being loading, but the structure did not collapsed. During later big displacement cycles loading stage, though infilled silicate bricks of second storey wall of specimen KZML-2, KZML-3, and KZML-4 desquamated in a big area, steel bars of rib beams yielded, and second storey multi-ribbed wall slab degenerated into beam-hinged frame only being composed of inner frame (made up of rib beams and rib columns) and outer frame, the specimens could still bear vertical load, did not arise collapsed, and displayed ductility failure characteristic.
Coefficient of ductility is an index of reflection of deformation capability after structure or component entering yield stage, expressed as:

$$\mu = \frac{\Delta_m}{\Delta_y} \qquad (3.2)$$

where the μ is coefficient of ductility; Δ_m is the maximum displacement of specimen, taking corresponding displacement value while load descend to 85% of ultimate load in skeleton curves; Δ_y is the yield displacement of specimen.
The coefficient of ductility of specimen KZML-1, KZML-2, KZML-3, and KZML-4 is 4.5, 3.2, 2.1 and 2.5 respectively. It can be seen that the coefficient of ductility of frame-supported multi-ribbed slab structure is big, and there is still a big deformation capability after structure yielding. Therefore, FSMRSS has a good earthquake collapse resistance capacity.

4. CONCLUSIONS

The pseudo-static experiments of the four scale specimens of frame-supported multi-ribbed slab structure (FSMRSS) have been carried out, in which there are three 1/2 scale two-storey two-bay models and one 1/3 scale three-storey two-bay model. The seismic performances of the structure under low cyclic loading, such as the failure procedure, failure mode, bearing capacity, deformation features, stiffness, hysteresis characteristic and anti-collapse performance, were studied. The results show that the specimens represent high load carrying capacity even in large deformation condition, favorable restoring characteristics, good ductility and earthquake collapse resistance capacity. The conclusion obtained provide reliable basis for the application of FSMRSS to buildings with large space at the bottom.

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